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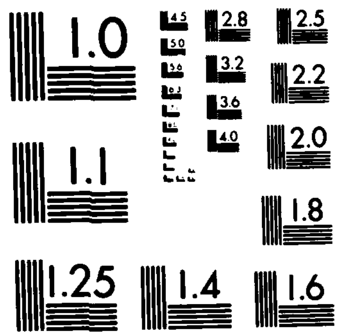

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Technical Evaluation Report on the Flight Mechanics Panel Symposium on Active Control Systems — Review, Evaluation and Projections

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AGARD Advisory Report No.220

TECHNICAL EVALUATION REPORT

on the

FLIGHT MECHANICS PANEL SYMPOSIUM

on

ACTIVE CONTROL SYSTEMS – REVIEW, EVALUATION AND PROJECTIONS

by

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This Advisory Report was prepared at the request of the Flight Mechanics Panel of AGARD.

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A TECHNICAL EVALUATION REPORT FOR THE SYMPOSIUM ON "ACTIVE CONTROL SYSTEMS - REVIEW, EVALUATION AND PROJECTIONS"

(Toronto, Canada, 15-18 October 1984)

by

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ABBREVIATIONS

ACS	- active control system	FBW	- fly-by-wire
ACT	- active control technology	FCS	- flight control system
AFTI	- advanced fighter technology integration	FDP	- Fluid Dynamics Panel of AGARD
DLC	- direct lift control	GCP	- Guidance and Control Panel of AGARD
EAP	- experimental aircraft program	HQ	- handling qualities
EM	- electromagnetic	PIO	- pilot induced oscillations
EMP	- electromagnetic pulse	STOL	- short takeoff and landing

1. INTRODUCTION

The advent of operational FBW control systems and digital computers suited for use in FCS has opened up a new era in aircraft design philosophy. The general heading "ACS" encompasses a wide range of full authority control functions carried out under the supervision of sophisticated on-board digital computer systems. The significant interaction of the ACS with all aircraft subsystems is such that it appears that the ACS may in future act as the central integrating focus during the aircraft design process. For this reason it is important that all those involved in this process be made aware of the potential benefits and problems associated with ACS.

The Flight Mechanics Panel of AGARD felt that recent progress in the ACS field was sufficient to justify a symposium devoted to this topic. The resulting symposium on "Active Control Systems - Review, Evaluation and Projections" was held at the Commerce Hall, Toronto, Ontario, Canada during 15-18 October 1984. The attendees numbered 148.

The applications of ACS discussed during the symposium touched on a wide range of topics:

- FBW
- digital computer systems
- stability augmentation of aircraft with reduced inherent stability
- increased maneuverability and performance
- gust alleviation
- structural load alleviation
- carefree maneuvering
- task-tailoring of aircraft configuration and control surfaces
- control over coupling effects
- integration of all aircraft subsystems
- use of ACT to solve developmental problems

An advanced ACT based fighter is likely to incorporate the aerodynamic features of the EAP aircraft of Figure 1. In order to ensure the high level of integrity required of a primary FCS there must be redundancy built into the system. This can be achieved by incorporating multi-lane and self-monitoring features within the system architecture as shown in Figure 2. In the case of multi-lane redundancy at least three duplicate channels must be employed in order to allow a faulty lane to be detected through a channel comparison process. That is, when a significant difference is detected among the three channels, the one that differs from the other two is shut down and the system is reduced to one of two channels. Of course, once this occurs the system cannot isolate any further faults through a comparison process. Self-monitoring refers to a process where a device detects faults within its own structure without employing any external references. A combination of multi-lane architecture and self-monitoring can also be used to achieve the desired reliability. Figure 3 depicts the anticipated catastrophic failures per flight hour (PFH) for a three lane FCS with self-monitoring on all lanes. The lane mean time between failures (MTBF) refers to each channel in isolation. The % monitor effectiveness refers to the average percentage of internal failures that the monitor will catch. As seen in the figure the effectiveness of such schemes is limited by the state of technology in these fields.

The technology is maturing and a considerable amount of practical experience has been gained in the use of ACT. This is reflected in the significant number of flight

test programs (both underway and completed) reported on during the symposium. They include:

(1) BO 105 helicopter
(2) (AFTI) F-16
(3) X-29A
(4) F-104G
(5) FBW Jaguar
(6) Hunter MK.12
(7) F/A-18A
(8) Do 28 TNT
(9) L-1011
(10) Space Shuttle

The continued commitment to the further development of ACT can be seen in the list of planned flight test programs described in a number of papers:

(1) active undercarriage system to be installed on a fighter aircraft
(2) BAC-111 FCS
(3) A-310, A-320 programs
(4) EAP
(5) AFTI/F-111
(6) F-15 STOL and maneuver technology program

2. SUMMARY OF SYMPOSIUM PAPERS

The Symposium consisted of five sessions followed by a round table discussion. The following account attempts to briefly give the flavor of the contents of each paper and comments from the audience where appropriate. Each paper is presented in numerical order according to its assigned symposium number.

2.1 Session I - Introduction

(1) Active Control Technology - Past, Present, Future (GCP Contribution).
M. Pelegrin, CERT, Toulouse, FR

This review paper touched on a wide range of topics related to ACT. In a sense it provided the first contact in the symposium with most of the topics contained in the papers to follow. Areas of discussion included hardware, software, applications of ACT and reliability considerations.

(2) The State-of-the-Art and Future of Flight Control Systems (GCP Contribution).
R. Quinlivan, General Electric, USA

The evolution of ACT from early stability augmentation systems to current full authority flight control systems was covered. The philosophy behind the design of current and future ACS was presented in a manner that highlighted both the benefits and the problems involved. The potential hazards inherent in reverting to a backup FCS following a total failure of the primary system were discussed.

2.2 Session II - Procedures and Applications

(3) A Perspective on Superaugmented Flight Control Advantages and Problems.
D. McRuer, D. E. Johnston and T. T. Myers, STI, USA

A superaugmented FCS can both stabilize an unstable aircraft and provide novel effective vehicle dynamics. This paper dealt with the longitudinal dynamics of such an aircraft and FCS. The Total Available Gain Range (TAGR) factor was presented as a basic measure that relates degree of instability, control system limitations, and key control system adjustments. The flying qualities of superaugmented aircraft were discussed and were highlighted in the question period which followed.

(4) Aspects of Application of ACT Systems for Pilot Workload Alleviation.
K. Wilhelm and B. Gmelin, DFVLR, GE

Aspects of the application of ACT systems for pilot workload alleviation were described for both fixed-wing aircraft and helicopters. The work involved wind tunnel tests of a rotor vibration control system and flight tests of a helicopter control decoupling system. Flight tests in the HFB 320 in-flight simulator have been carried out on DLC incorporated within two flight path control techniques. It was found that DLC can only improve flight path control capability without HQ degradation if the pilot is supported by an inner loop augmentation system such as a Rate Command/Attitude Hold (RC/AH) system. Tests carried out in the same aircraft showed the influence of FCS time delays of up to 1.3s in degrading HQ ratings.

(5) Application of AFTI/F-16 Task-Tailored Control Modes in Advanced Multirole Fighters. R. D. Toles, Gen. Dynamics, USA, D. R. McMonagle, Edwards AFB, USA, and D. C. Anderson, Gen. Dynamics, USA

This paper described flight tests carried out with a highly modified F-16 aircraft

to demonstrate the effectiveness of a digital FCS and task-tailored modes (both conventional and unconventional). It dealt specifically with how task-tailoring the longitudinal control laws provided improved HQ for the air-to-air and bombing missions, how a flat turn mode gave the pilot an added advantage for the bombing and strafing tasks, and how Level 1 HQ for the landing system have been obtained. The key to the flat turn mode is zero sideslip during the maneuver to reduce the aerodynamic load on the stores carried. The presentation was highlighted by an informative film.

(6) X-29A Digital Flight Control System Design. A. B. Whitaker and J. Chin, Grumman Aerospace, USA

This paper outlined the structural and control elements going into the design and construction of this unique test aircraft incorporating a forward swept wing. Flight testing is expected to begin soon. A number of ACT related concepts were included such as relaxed longitudinal stability, triplex digital FBW system and high gain FCS, a DLC type of response, task-tailoring, drag minimization and an analog backup FCS.

(7) The Evaluation of ACS for Helicopters: Conceptual Simulation Studies to Preliminary Design. J. S. Winter, G. D. Padfield and S. L. Buckingham, RAE, UK

The means by which design aims may be defined were investigated along with how they may be implemented through to the preliminary design stage. The use of a simplified helicopter model in a ground-based simulator (called conceptual simulation) has been demonstrated to provide a quick means of studying control problems. A possible control law design for a helicopter was described. The paper closed with the outline of a technique for assessing the robustness of a control system design in the face of unknown or varying elements in the aircraft state matrix. This method, based on the use of maximum singular values, appears to be a very useful design tool.

(8) ACT Applied to Helicopter Flight Control. W. R. Richards, Smiths Industries, UK

This paper identified ACS configurations suitable for installation in the 1988 and 1992 time scales. Brief discussions of reliability aspects, control law philosophy and the impact of advanced technology were presented. It appears that fibre optics and the replacement of electrical devices by optical ones where possible will be required to meet the challenge of EMP/EMC and lightning strikes.

2.3 Session III - Experiences

(9) Some Flight Test Results With Redundant Digital Flight Control Systems. U. Korte, MBB, GE

The successful flight test program carried out in a modified F-104G was outlined. A digital quadruplex FBW and FCS was used to stabilize the airframe which was destabilized longitudinally by the addition of aft located ballast and a canard surface. 176 flights were completed in which the successful operation of the FCS was demonstrated along with reversion to a simplified digital backup system. Contrary to the doubts expressed by some others at the symposium, the author indicated that he feels that FCS software verification is not as great a problem as many think and that reversion to a properly implemented backup FCS can be handled by pilots in an operational environment.

(10) An Update on Experience on the Fly by Wire Jaguar Equipped With a Full-Time Digital Flight Control System. E. Daley, BAe, UK

This was a technology demonstration program and the presentation emphasized relaxed stability, carefree maneuvering and protection against EM interference in the form of lightning and high frequency radio signals. The quadruplex FBW system had no mechanical backup. The FCS was successfully demonstrated during close to 100 flights and the EM immunity of the complete system was proven during extensive ground tests. The presentation included a film record of the flight test program. The author concluded with the very encouraging statement that, "both customer and aircraft manufacturer are now confident that active control systems can be implemented safely and cheaply with similar integrity to present day mechanical systems, and that the aircraft can be acceptably hardened against natural and man-made EM interference".

(11) ACT Flight Research Experience. D. J. Walker, BAe, UK, and R. M. Horner, RAE, UK

The Hunter ACT aircraft development and flight test program was reviewed. A number of practical hardware aspects of the project were discussed. The FCS in-flight tests included a non-linear pitch filter (with an effect much like the pitch axis task-tailoring of Paper #5) and a depressed roll axis (about the sight axis). Mixed success in using ground-based simulators during system development was reported.

(12A) Operational and Developmental Experience With the F/A-18A Digital Flight Control System. W. A. Moran, McDonnell Aircraft, USA

This paper described an operational aircraft making full use of ACT. Of

particular interest was the use of the digital FCS to help solve several developmental problems encountered during the flight testing of the F/A-18A. Four problems were highlighted: poor nosewheel liftoff characteristics; insufficient roll performance; excessive structural loads; unwanted roll coupling. All these difficulties were overcome in a unique and cost-effective manner with the help of the digital FCS. Also of interest was the manner in which the system designers managed to reduce an unacceptably large FCS time delay to a reasonable value of 70 ms.

(12B) Flight Testing and Development of the F/A-18A Digital Flight Control System. R. A. Burton and B. T. Kneeland, NATC, USA; and U. H. Rabin and R. S. Hansen, Systems Control Technology, Inc., USA

A new technique was presented for extracting equivalent system models, which uses several algorithms including a maximum likelihood estimator method. This and the use of closed-loop pilot mission-related task testing have been successfully employed to evaluate the FCS during its development. During the discussion following the paper, the authors stated that the use of the equivalent model was recommended for ground-based simulation during the design phase (this is similar to the conceptual simulation proposal of Paper #7).

(13) OLGA - An Open Loop Gust Alleviation System. H. Bohret, Dornier, GE; B. Krag and J. Skudridakis, DFVLR, GE

Following sophisticated wind tunnel trials, a flight test program was carried out using a Do 28 TNT aircraft to evaluate the effectiveness of an open-loop gust alleviation system. By using an open-loop approach the basic airframe dynamics were left unaltered. Excellent results were reported. Excitation of the wing's first bending mode by the system was removed by employing a suitably tuned notch-filter. It was found that the suppression of low frequency accelerations by the OLGA system made the passengers more conscious of other sources of discomfort.

(14) Demonstration of Relaxed Stability on a Commercial Transport. J. J. Rising, W. J. Davis and C. S. Willey, Lockheed, USA

The application of relaxed stability to current transport aircraft can lead to a 2% drag reduction. This can rise to 4% for next generation aircraft. A flight test program and a ground-based flight simulator program employing an L-1011 aircraft have demonstrated the successful implementation of this concept. Stability augmentation was provided by a digital FCS and HQ ratings were obtained for a range of conditions. It was concluded that, "careful tailoring of the augmentation system authority will result in acceptable failure characteristics, thereby eliminating the need for multi-system redundancy".

(15) Realisation of Relaxed Static Stability on a Commercial Transport. U. P. Graeber, MBB, GE

This paper dealt with the use of fuel transfer to an aft located tank in order to reduce the trim drag on a commercial transport. Both ground-based simulator trials and flight tests in an Airbus A300 were employed to demonstrate that the aircraft could be flown both manually and by the autopilot with significantly aft c.g. locations. It was suggested that the use of such fuel transfer techniques is the only practical way to achieve reduced stability in an operational commercial transport.

(16) Active Control Technology Experience With the Space Shuttle in the Landing Regime. B. G. Powers, NASA Dryden Flight Research Facility, USA

An interesting description was provided of the development of the shuttle FCS. Of particular concern was a tendency to excite PIO during the landing phase. Both ground-based and in-flight simulation were used to study the problem. It was found that in-flight simulation was the only reliable method to use in the study of PIO. Two of the major contributions to the PIO problem were found to be system time delay and the lack of a clear motion cue at the pilot's location following a pitch up command. The PIO problem was solved by reducing the demands of the piloting task and introducing an adaptive stick gain limiter.

2.4 Session IV - Reliability, Survivabiliy, Certification

(17) The Aerodynamics of Controls (FDP Contribution). A. D. Young, University of London, UK

This paper gave a comprehensive review of the various conventional and unconventional control surfaces (or motivators) available for use as part of an ACT system. The point was made that the advent of ACS requires us to obtain a better understanding of the aerodynamics of such motivators in order to make effective use of them. In particular, dynamic effects and the influence of flight at high angles of attack and at transonic speeds on these devices needs further study. A better data base must be generated to aid the designer.

(18) Active Control Landing Gear for Ground Loads Alleviation. J. R. McGehee, NASA Langley, USA

An active landing gear has been created by connecting the hydraulic piston in an

oleo strut to a hydraulic supply. A controller modulates the pressure in the oleo to achieve the desired dynamic characteristics. Tests on ground rigs (documented by a film) have demonstrated the successful alleviation of induced structural ground loads and the next step will be a flight test using a fighter aircraft.

(19) Wing Buffeting Active Control Testing on a Transport Aircraft Configuration in a Large Sonic Tunnel. R. Destuynder, ONERA, FR

A very sophisticated large aeroelastic half-model has been developed to duplicate the structural characteristics of a typical civil transport aircraft. An active flaperon system has been developed to dampen out structural response to buffeting experienced at high angles of attack and/or Mach numbers in the range 0.50-0.82. This was achieved without increasing the structural modal frequencies. The resulting reduced structural strain and airframe motion effectively increase the usable flight envelope.

(20) A Modular Dissimilar Redundant Computer Designed for High Integrity Control. S. M. Wright, BAe, UK and R. G. Burrage, Lucas Aerospace, UK

In order to apply modern digital hardware in a full authority high integrity control system, suitable precautions must be taken to avoid the consequences of a common mode data dependent error in a multi-lane system. A pseudo code based dissimilar modular multiprocessor design was described as a possible routine way of applying dissimilar techniques and hardware at minimum cost. A safety map approach was developed to aid the designer in selecting the system architecture.

(21) How to Handle Failures in Advanced Flight Control Systems of Future Transport Aircraft. M. F. C. van Gool, NLR, NE

This paper described a ground-based simulator program in which reversion to an unstable FCS backup occurred following the failure of the primary system. Of interest was the large scatter in the HQ ratings given to the backup system. It was found that existing longitudinal HQ criteria have difficulty in explaining the trend in pilot ratings. It was concluded that the certification of future ACT based transport aircraft will be a very complicated task.

(22) Interactive Design of Specifications for Airborne Software Set (GISELE). J. Choplin and D. Beurrier, Avions Marcel Dassault-Breguet Aviation, FR

GISELE is an FCS software development process/system that possesses the features needed to generate production level certifiable software. It was designed to assist the user at all stages of development and testing and to generate the required level of documentation. It has been in use since 1983.

(23) The Certification of Airborne Complex Digital Systems. P. Toulouse, Aerospatiale, SNI, FR

This paper presented an overview of how the certification process might be applied to future ACT based aircraft. Present regulations (FAR/JAR 25) are not very specific as to how compliance with safety considerations might be carried out. Presently more specific regulations (e.g., AC/ACJ 1309 and RTCA DO 178/EUROCAE ED. 12) are being developed in which step by step procedures are proposed. Demonstration of compliance will require a combination of risk analysis, software analysis and ground test reports. The author feels that all software maintenance should be under the control of the original designer.

2.5 Session V - New Studies, Future Projections

(24) The Flight Control System for the Experimental Aircraft Programme (EAP) Demonstrator Aircraft. J. Kaul, MBB, GE, F. Sella, AIT, IT, and M. J. Walker, BAe, UK

The historical background of the EAP was presented. The planned aircraft was described under the headings: aerodynamics; FCS design; and control laws. Because the first flight is planned for May 1986 the FCS design is based on previously proven technology. The aircraft is intended to demonstrate: advanced structures and materials; advanced aerodynamics; ACT; digital data bus; modern cockpit; stealthiness; and digital control of the engine.

(25) Automatic Flight Control Modes for the AFTI/F-111 Mission Adaptive Wing Aircraft. M. R. Evans, R. J. Hynes, D. C. Norman, and R. E. Thomasson, Boeing, USA

This program involves the fitting of an experimental F-111 with a variable-camber wing and a digital FCS that makes use of this feature. The following automatic modes have been implemented: (i) Maneuver camber control - to maximize lift/drag. (ii) Cruise camber control - to maximize horizontal velocity. (iii) Maneuver load control - to reduce wing root bending. (iv) Maneuver enhancement and gust alleviation - uses variable camber and the horizontal tail to increase maneuver response and to reduce gust response. Flight tests are to begin in 1985.

(26) The STOL and Maneuver Technology Program Integrated Control System Development. D. J. Moorhouse and D. R. Selegan, Wright-Patterson AFB, USA

This is a technology demonstrator project much like the EAP of Paper #24. The goal is to add STOL capability to a supersonic fighter and to enhance combat mission performance by using the same technologies. This will be accomplished by employing a level of control integration beyond any attempted so far. In particular a highly modified propulsion system will be incorporated as a primary control element. The authors state that, "the control system design will require an integrated team of aerodynamics, stability and control, flying qualities, guidance, display, propulsion and controls specialists". The test aircraft will be an F-15 and the project will extend over the next 4-5 years.

(27) The Evolution of Active Control Technology Systems for the 1990's Helicopter. G. C. F. Wyatt, Westland Helicopters Ltd., UK

This paper reviewed the application of ACS in helicopters with a view towards determining how the civil market could benefit from military develoments. System failures and how best to deal with them were discussed. The author emphasized the need for: (i) Considering civil ACT applications when undertaking military R and D. (ii) More study of the common mode failure problem. (iii) Increased flight testing of ACT aircraft.

3. ROUND TABLE DISCUSSION

Following the presentation of papers a round table discussion was held under the chairmanship of Mr. R. C. A'Harrah, NADC, USA. The panel members were:

M. Pelegrin, CERT, Toulouse, FR
R. Quinlivan, General Electric, USA
B. Etkin, UTIAS, CAN

The discussion began with the chairman posing a hypothetical question to each of the panelists in turn. Their responses formed the basis for a lively question and answer session involving the panelists and the audience. The following is an approximate record of the proceedings.

3.1 Question Posed to M. Pelegrin

You are responsible for the design of a new aircraft constructed from non-metallic composite materials and incorporating an ACT-based FCS. How can you minimize the influence of severe EM interference (such as EMP or lightning strikes) on the FCS? Under the worst EM disturbance conditions how can you ensure the safe return of the aircraft to base?

Response by M. Pelegrin:

Present documentation concerning EM disturbances was derived for aircraft with metallic structures and thus it is not obvious that their recommendations apply for non-metallic composite aircraft. Following an EMP of short duration (on the order of 1 ms) the second pulse in the transient EM field induced in a metallic aircraft often causes the greatest damage. In the case of a non-metallic composite aircraft it is the first pulse that causes the most problems, thus there is a fundamental difference between the two cases.

Tests performed on ground rigs can provide a rough approximation to in-flight EM effects. Self-correcting computer codes can be used to overcome any single bit errors in computer memory caused by a short duration initial EM pulse. One way to minimize the likelihood of EM energy reaching a device is to replace electrical conductors by fibre optic strands. Because devices such as computers, sensors and actuators require energy inputs, usually supplied by some form of conductor, there is often an additional path over which electrical impulses can reach sensitive equipment. This problem might be alleviated by having such devices powered by internal energy sources and ensuring that non-metallic hydraulic tubing is employed at the device interface.

Because there is a correlation between the presence of lightning and turbulence in the atmosphere it would be wise to ensure that any critical gust alleviation system is well-protected from EM disturbances. If lightning is anticipated it would make good sense in an aircraft with relaxed longitudinal stability to transfer fuel forward to increase the inherent stability. A redundant inertial navigation system should have one INS platform feeding the FCS with no metallic connectors to the outside. A second INS with well-shielded cables could be used to drive the pilots' instruments. Of potential benefit would be an instrument to measure the electrical potential in the atmosphere near the aircraft. This could give the pilot a warning of possible lightning strikes and thereby allow him to take suitable precautionary steps.

3.2 Question Posed to R. Quinlivan

A new fighter aircraft is under development which employs ACT to the fullest extent. The project faces both time and cost constraints. As manager of the handling qualities and flight control groups involved what would you do to get the maximum return with limited resources?

Response by R. Quinlivan:

First I would determine the specifications for the system including current HQ criteria. The latter would serve as a guide only, because they may not ensure satisfactory results. I would employ ground-based flight simulator trials. Because of the presence of unwanted time delays in such simulators (which can have an adverse effect on HQ ratings) I would also employ in-flight simulators as part of the program. For evaluation purposes I would employ a number of critical tasks such as air-to-air combat, carefree maneuvering, precision pointing and the landing task.

In formulating the control laws I would use classical techniques if the aircraft is similar to past designs and I would have the flying qualities people look at the proposed solution. I would recommend that the purchasing agency form a team for the purpose of carrying out critical design reviews starting at the HQ specification stage. They would act as a group of skeptics in the overall process. The simulator test and flight test programs should be carried out jointly by two groups of pilots, a design group and an evaluation group.

3.3 Question Posed to B. Etkin

Two types of engineers are often intimately involved in the ACT area, handling qualities engineers and control system engineers. It is found that the two groups often fail to properly communicate with each other and in the past this has resulted in increased program costs, slipped schedules, and even fatal aircraft accidents during the development program. It is suggested that perhaps this lack of communication is the fault of the engineering schools. How could these schools help solve this problem?

Response by B. Etkin:

As a former dean of engineering I have had to respond many times over the years to such questions from the industrial sector. Practitioners of specialties such as aircraft control systems, and indeed all the other areas that constitute aeronautical engineering, often come to regard their contribution to an overall design as playing the dominant role. Such internal tensions have been faced before by the industry, for example between the structures and the aerodynamics groups, and may in fact reflect a healthy dedication to one's discipline. The chief designer must see to it that all the various groups work together in balanced harmony.

It is all too easy to blame the universities for these difficulties. However it must be realized that it is not possible for universities to train students fully in all the various areas in which they may be involved at some time in the future. We instill attitudes. We ensure that the graduating engineer has a sufficient grounding in the basics to allow him to cope with a wide range of topics. In the aerospace industry many control sytem specialists are graduates from electrical engineering departments while many handling qualities people have been trained as aeronautical engineers. The problem of resolving any tensions between the two groups is the job of industry.

Universities could help in establishing the desired harmony by providing short courses designed to broaden the backgrounds of both groups. However, such a program should be initiated by requests from the industrial sector.

3.4 Discussion Period Summary

It is possible to shield non-metallic composite aircraft from EM effects by covering them with foil but there is an obvious weight penalty.

Non-electronic FCS backup might be provided by fluidic devices and direct fibre optic inputs to hydraulic actuators in the future.

Tests have been successfully carried out using a free-floating canard to increase aircraft stability.

The use of ground-based simulators in FCS development has resulted in HQ problems in several recent designs employing ACT. There should be a mix of ground-based and in-flight simulation.

The verification of new ideas on aircraft with similar properties already in the inventory would be useful.

Designing ACT aircraft to the MIL SPEC does not always work. Often this is the result of choosing the wrong equivalent system.

Perhaps more HQ research could be carried out in the universities on how to generate good HQ results based on MIL SPEC data.

Our current HQ data base is based on second order systems and may not be appropriate for all higher-order systems.

Universities should produce a generalist who thinks of the product. He will carry out the necessary systems integration as a "designer".

4. CONCLUSIONS

(1) ACT has been demonstrated to be capable of producing a wide range of beneficial improvements in both military and civilian aircraft. This has resulted from the simultaneous development of FBW control systems and digital FCS computers.

(2) The use of relaxed inherent longitudinal stability can be used to reduce trim drag which in turn leads to increased range and performance. ACT systems can then be used to artificially stabilize the aircraft to produce acceptable HQ.

(3) ACT can be used to coordinate the actions of a number of aerodynamic and powerplant controls to improve conventional aircraft performance as well as to introduce new and useful flight modes to serve specific mission requirements.

(4) Significant reduction of turbulence-induced aircraft response is possible through the use of ACT. By implementing this process in an open-loop manner the basic aircraft HQ are not affected.

(5) Aircraft structural loads due to maneuvering and arising from turbulence and boundary layer effects can be reduced by ACS thereby increasing the fatigue life of the aircraft. The same technology can also be applied to reduce structural loads due to ground maneuvering when it is employed in an active control landing gear system.

(6) Carefree maneuvering can be achieved by employing ACT. Angle of attack and g limiting can be used to prevent departures and structural damage. Spin recovery can be implemented for use during the aircraft testing phase.

(7) The aircraft configuration and control surface deflections can be continuously updated under ACS control to achieve optimum performance. This can be carried out much more effectively than under human control.

(8) Coupling of the aircraft response axes can be modified by ACS to provide improved HQ. This may take the form of uncoupling or the introduction of desirable coupling.

(9) The ACS can be used to provide the overall integration of an aircraft's many subsystems in order to increase its effectiveness in performing a range of missions.

(10) Developmental problems with an aircraft can be overcome in a cost effective manner by a combination of software changes to its ACS and modest hardware changes. The presence of the ACS helps to reduce the number of hardware modifications required.

(11) The combined effect of items (1) through (10) above tends to reduce pilot workload and improve the aircraft ride qualities thereby improving the environment in which flight crews operate.

(12) The use of digital FCS carries with it the penalty of introducing additional system time delay. Because system time delay degrades HQ it must be kept to a minimum. This possibility has been demonstrated in several successful aircraft designs. Indeed, in the case of the F-18 the time delay problem was mostly attributed to the control laws themselves — not the digital FCS.

(13) The creation of new aircraft flight modes by the ACS will require additional pilot training. It has been shown that pilot training under these conditions can lead to pilot acceptance of flight modes which initially were judged to be unacceptable. However, system response may be degraded as was found with the Space Shuttle touchdown performance.

(14) Reversion to a backup FCS following the total failure of the primary system was a topic of considerable discussion at the symposium. Although this process has been successfully demonstrated during several flight test programs, doubt still remained as to how well this would work under operational conditions.

(15) In general, success was reported on the application of existing techniques and standards for establishing the acceptability of flying qualities for highly augmented aircraft. However, there still remains a feeling that new standards and new techniques must be developed, in order to fully realize the benefits of ACT.

(16) The implementation of ACT requires the application of a wide range of aerodynamic motivators (control surfaces). At the present time there is a need to improve the data base on these devices, particularly in the areas of dynamic effects and interference effects.

(17) FCS reliability appears to be one of the most difficult problems facing the further development of ACT. The problem is both in implementing the system in a cost-effective manner and in proving the level of reliability in a positive manner when the design failure rate is in the range of 10^{-7} to 10^{-9} failures per flight hour.

(18) FCS reliability can be achieved by a combination of multiple redundancy (with cross-checking between lanes used to detect failures) and self-monitoring channels (which becomes necessary when multiple lane failures prevent the cross-checking process).

(19) Common mode FCS failures are a real danger because lane cross-checking cannot detect an error which is common to all lanes. Common mode failures can result from the original system specification, the software package, the computer hardware, or from external sources such as EM disturbances.

(20) Protection of the ACS against EM disturbances can probably be adequately handled with current technology for conventional all-metal aircraft. In the case of non-metallic composite structure aircraft, further developments will be required.

5. RECOMMENDATIONS

(1) There should be continued support of flight test programs devoted to ACT. It was apparent during the present symposium that the significant amount of practical experience gained from such flight tests is pacing the development of ACT.

(2) The demonstration of ACS reliability as part of the acceptance or certification process appears to be a major problem. Further work in this area should be carried out in conjunction with all those individuals who are involved. Perhaps trial acceptance or certification programs should be carried out along with the development of currently planned flight test aircraft. This should be organized so that the certification personnel are actively present from the design phase onward.

(3) Further work on developing HQ specifications for highly augmented aircraft is needed. This will require a coordinated program of analysis, ground-based and in-flight simulation trials.

(4) The usefulness of a backup FCS appears to be uncertain. An analysis should be carried out of past experience with such systems in order to determine the best form for a backup FCS and the conditions under which a successful reversion to the backup can be achieved. Further flight testing will be required.

(5) Further development of techniques for shielding against EM disturbances is required, particularly in the presence of non-metallic aircraft structures. Probably fibre optics and optical devices will be needed to replace conventional electronics where possible.

(6) The data base on motivators (such as control surfaces) should be expanded. This will require the systematic gathering of past research results and the extension of this work. In particular, dynamic effects and interference effects should be covered.

(7) FCS and HQ engineers must learn to cooperate in the development of ACT-based aircraft. This can be achieved through a combination of in-house industrial organization and short courses held in a university setting.

(8) Interaction between aerospace firms and microcomputer and chip manufacturers should be encouraged in order to develop digital systems with improved reliability.

(9) Current in-flight simulator facilities should be supported and upgraded so that they may continue to play an active role in the development of ACT.

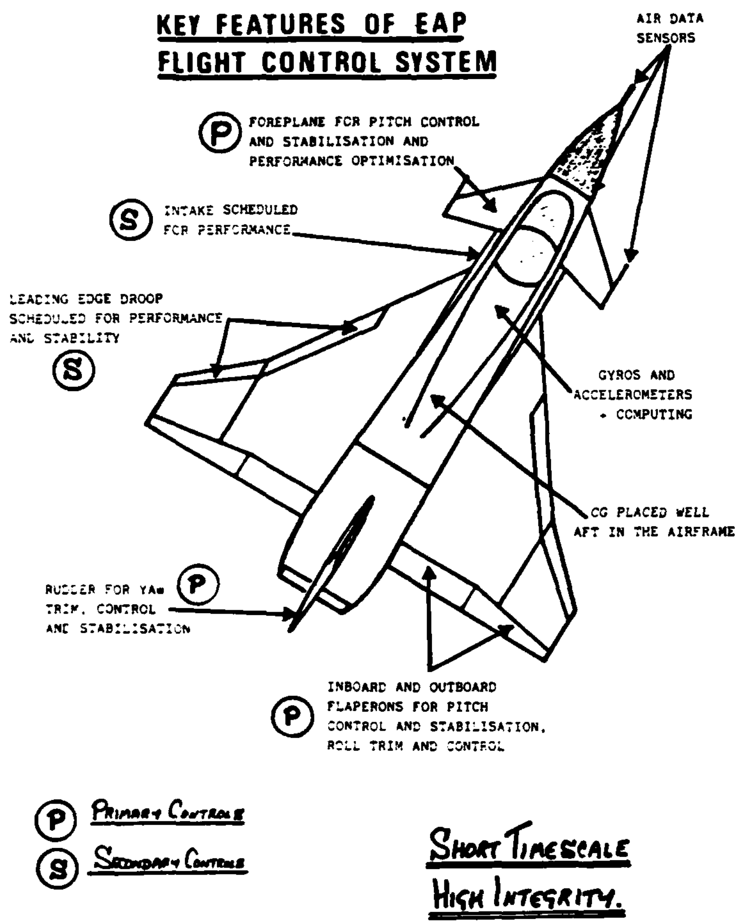

Figure 1 ACT Fighter Aircraft (from Paper #24).

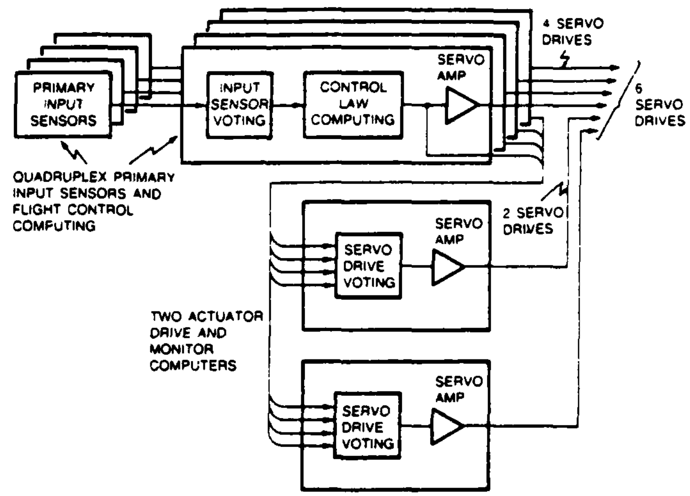

Figure 2 FCS Architecture (from Paper #10).

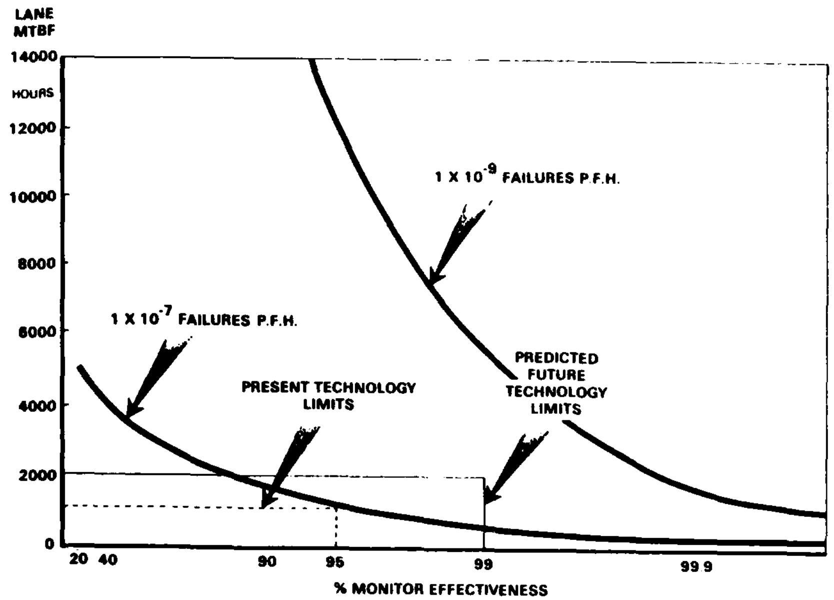

Figure 3 Monitored Triplex System (from Paper #27).

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14. Abstract

The Symposium was held in Toronto ~~Canada, during~~ 15—18 October, 1984. It was attended by 148 people. 27 papers were presented on various topics related to active control technology. The meeting was highlighted by a number of reports on actual flight test experience with active control systems. The contents of the papers taken as a group provide an extremely useful summary of current knowledge in the field and indicate the direction that future research should take. The discussion periods went very well with a high level of audience participation which added both interest and content to the proceedings. From the papers and discussions several areas emerged as requiring urgent further study. These included: handling qualities specifications; the use of flight control system backups; the development of high integrity systems at reasonable cost; and the demonstration of system reliability. The symposium closed with a highly successful round table discussion.

NA

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